ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ92-329

EVALUATION OF BRIDGE APPROACH RAILS

Final Report

Prepared by:
Roger P. Bligh
Dean L. Sicking
Lance Bullard
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

May 1992

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AZ92-329		

4. Title and Subtitle

EVALUATION OF BRIDGE APPROACH RAILS

5. Report Date

May 1992

6. Performing Organization Code

7. Author(s)

Roger P. Bligh, Dean L. Sicking, L. Bullard

8. Performing Organization Report No.

Research Report 7155-1F

9. Performing Organization Name and Address

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No.

11. Contract or Grant No.

HPR-PL-1(37)329

12. Sponsoring Agency Name and Address

Arizona Department of Transportation
206 S. 17th Avenue
Phoenix, Arizona 85007

13. Type of Report and Period Covered

Final: January 1990 to May 1992

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A recent study on the performance of guardrail-to-bridge rail transitions revealed that many widely used designs do not meet current safety standards. As a result, the Federal Highway Administration (FHWA) requested that the Arizona Department of Transportation verify the safety performance of its standard transition designs. Three transition designs currently being used by ADOT were evaluated through a combined program of computer simulation and full-scale crash testing. The standard ADOT wood post transition, incorporating a channel rubrail and two different sizes of timber posts at a reduced post spacing near the bridge rail end, was found to be in compliance with National Cooperative Highway Research Program (NCHRP) Report 230 performance criteria. The standard ADOT steel post transition with channel rubrail was also found to be in compliance with NCHRP Report 230 requirements when impacted near the end of the bridge rail. However, the upstream end of the steel post transition required modification to eliminate deficiencies identified during testing. The modified design, which terminated the channel rubrail behind a W6x9 guardrail post, was successfully crash tested.

The third transition design evaluated was the standard ADOT steel post system with a 6 inch curb extending along the length of the transition. When tested, this system failed to meet NCHRP Report 230 test criteria. Significant modifications were made to the design including the addition of a rubrail section and tubular steel blockouts near the bridge end. This modified design was successfully tested in accordance with NCHRP Report 230 recommendations. In an effort to assess the risk posed by the current design, an additional test on the unmodified system was conducted using impact conditions of 60 mph and 20 degrees. The steel post system with curb successfully passed this crash test, indicating that there is no need to establish a retrofit program. It is recommended that the wood and steel post systems with curb, as well as the steel post system with rubrail and without curb, be retrofit or replaced as they are damaged and reconstructed.

17. Key Words	18. Distribution Statement	23. Registrant's Seal
approach rail, transition, guardrail, bridge rail/parapet, computer simulation, crash test, highway safety	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161	Registered Professional Engineer (Civil) CERTIFICATE NO. 24602 DEAN L. SICKING Date Signed 6-30-93 ARIZONA, U.S.A.

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified	193	

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

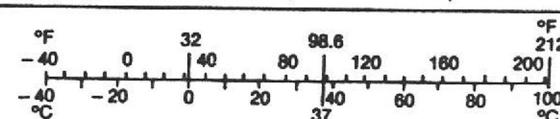
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

During the time when steel and aluminum bridge rails were common, numerous transition designs were implemented throughout the country. These relatively flexible bridge rails were not as demanding on transition designs as today's concrete barriers and, for this reason, little effort was directed at identifying the necessary stiffness or the critical impact conditions for these approach barriers. However, as rigid bridge rails such as the concrete safety-shaped barrier (CSSB) replaced metal designs, early transition standards were often retained.

In a recent study (1), a major crash test program was undertaken to evaluate the impact performance of guardrail-to-bridge rail transitions, many of the widely used designs were found to be inadequate. In an effort to eliminate this problem, the Federal Highway Administration (FHWA) issued Technical Advisory (TA) T5040.26 on the subject of guardrail transitions in January of 1988. Contained within this TA was a description of several transition systems which were successfully crash tested. The FHWA directed all state highway agencies to either adopt one of the tested designs or demonstrate the safety of their standard designs through full-scale crash testing. As a result, the Arizona Department of Transportation (ADOT) contracted with the Texas Transportation Institute (TTI) to analyze and test their standard designs.

Thus, the primary objective of this study was to evaluate the safety performance of ADOT's guardrail-to-bridge rail designs and to develop and test retrofit design modifications to alleviate the deficiencies of systems identified as substandard. The research approach, analysis procedures, and full-scale crash test results are presented in the sections which follow.

RESEARCH APPROACH

The basic configuration comprising the ADOT transitions incorporates a W-beam rail element mounted on posts with a reduced spacing of 3 ft.-1 1/2 in. The W-beam rail extends 12 ft.-6 in. onto the traffic face of the concrete bridge parapet at which point it is terminated with a standard 10 ga. terminal end shoe. Specially fabricated steel blocks spaced at 3 ft.-1 1/2 in. are used to block out the W-beam from the face of the concrete barrier. The steel spacers are connected to the concrete parapet using fabricated steel anchors embedded in the concrete. The concrete bridge rail is 32 inches in height and has a standard safety-shaped profile. Although the upper face of the barrier is maintained at a constant slope, the lower slope of the barrier transitions to a vertical wall over the last 12 ft.-6 in.

The ADOT transition systems which were evaluated in this study were essentially variations of this basic design. The variations include the use of either steel or wood guardrail posts in conjunction with either a lower rubrail or curb. The rubrail option incorporates a 25 ft. section of C6x8.2 rubrail mounted at a height of 12 inches. The rubrail is attached to every other post in the transition and is anchored to the concrete barrier. The curb option has a 6 inch curb which extends from the concrete barrier. The face of the curb aligns with the traffic face of the W-beam barrier. Both steel and wood guardrail posts can be used with these systems. The steel post systems utilize two W8x21 structural steel posts with an embedment depth of 68 inches adjacent to the concrete bridge rail to help transition the lateral of the guardrail. The other five posts in the transition are standard W6x9 posts with a 44 inch embedment. The W-beam rail is mounted at a height of 27 inches and is blocked out from the posts using standard W6x9 steel blockouts.

The first two posts adjacent to the concrete barrier in the wood post option are 10"x10"x6'-6" timbers with an embedment depth of 50 inches. The additional posts in the transition are 8"x8"x5'-4" with a standard embedment of 36 inches. The W-beam is blocked out from these posts using 6"x8"x14" wood blocks. It should be noted that, in order to accommodate the dimensions established by the rubrail and steel spacer blocks on the face of the concrete barrier, the blockouts are oriented sideways. Thus, both the steel and wood post systems provide a blockout distance of 6 inches.

These transition systems showed promise for meeting the test requirements of National Cooperative Highway Research Program (NCHRP) Report 230 (2). Use of a rubrail and blockouts minimizes the potential for wheel snagging on the guardrail posts or bridge rail end and the stronger posts immediately upstream from the bridge end help limit dynamic deflections and, thus, prevent vehicle pocketing. However, there were some concerns that warranted the analysis, testing, and evaluation of these designs. For instance, the single W-beam rail element had the potential for yielding locally and permitting structural components of the vehicle to snag on the fabricated steel blocks and/or the end of the concrete bridge rail. The ability of the concrete insert assemblies and rubrail anchorage to withstand a severe impact was also a concern. Additionally, it was uncertain to what extent the presence of the curb would degrade the performance of the transition.

The only way to definitively determine if a transition design can comply with current impact performance standards is through full-scale crash testing. However, in order to help establish a rational test matrix and eliminate the need for unnecessary full-scale tests, computer simulation techniques were used to augment the crash test program. Using computer simulation, a preliminary analysis of the transition systems was performed to identify potential weaknesses and to determine critical impact locations for each system. Additionally, when a system was found to be substandard, computer simulation was used to evaluate potential improvements and to help identify the limits of performance of the existing system.

The computer simulation model used in this study was the Barrier VII program (3). Barrier VII has been used very successfully for analyzing and designing a number of transitions from flexible to rigid barriers (1,4,5,6). The program has been proven to accurately predict maximum barrier deflections and degree of snagging, and to identify critical impact locations for various transition designs.

It should be noted that special considerations had to be taken into account when modeling the W-beam attachments on the face of the concrete barrier. Due to the presence of the fabricated steel blocks in the ADOT designs, the W-beam is initially free to deflect in the vicinity of the concrete barrier end. However, when the W-beam contacts the rigid barrier, a sudden high lateral resistance is developed. A series of pinned links and springs was used to model this behavior. Typical Barrier VII input used for the simulation of the ADOT transitions is shown in Appendix A.

After the transition designs had been modeled, the impact performance of each system was evaluated based on simulation results. The primary concern regarding the safety performance of a transition is that under severe impact conditions, the barrier will deflect sufficiently to allow pocketing or snagging on the end of the stiffer barrier. Vehicle pocketing is associated with excessive barrier deflections which permit the front of the vehicle to impact the end of the stiffer barrier. Snagging is a more common problem and can occur in two forms. A vehicle's wheel can contact a post or barrier end, or the stiff structural components of the vehicle can contact a barrier end, blockout, or post. Note that the point of impact can significantly affect the degree in which each of these events occurs. The critical impact point for a transition is defined as the location which maximizes wheel or frame snagging on the end of the stiffer system. Although NCHRP Report 230 recommends impacting a transition 15 feet upstream from the end of the second and more laterally stiff system, this number was not originally intended for transitions to rigid concrete barriers. Recent simulation and testing of transitions to rigid barriers has shown that the critical impact point for a transition to a rigid bridge rail is somewhat less than this value. In actuality, the critical impact location changes with the stiffness of the approach guardrail. Stiff approach barriers redirect impacting vehicles more quickly and, therefore, have a critical impact point nearer to the end of the rigid rail that do more flexible approach barriers.

Thus, the first step in the Barrier VII analysis was to determine the critical impact location for the ADOT transition designs. This was accomplished by simulating a number of impacts along the length of the barrier and determining which location maximized the potential for snagging on the exposed end of the bridge rail. The impact conditions used in these simulations corresponded to test designation 30 in NCHRP Report 230 which is the recommended test for evaluating the performance of a transition treatment. Test 30 is a structural adequacy test which involves a 4500 lb vehicle impacting the barrier at a speed of 60 mph and an angle of 25 degrees. These conditions examine the strength of the transition and its ability to contain and redirect an impacting vehicle.

Barrier VII indicated that the critical impact location for both the steel and wood post transition designs was approximately 6 ft. upstream from the end of the concrete barrier. This impact point was subsequently used for all simulation and testing of the ADOT transitions.

It should be noted that in most transition designs, a secondary transition exists at the point where the transition treatment begins and the standard guardrail ends. In the ADOT design, this point corresponds to the location where the rubrail begins. Barrier VII simulations of this upstream transition indicated that the critical impact location for a large car impact was approximately 10 ft. upstream from the beginning of the rubrail. These simulations evaluated the potential for wheel snagging on the end of the rubrail and on intermediate guardrail posts. The expected performance of this system, based on the simulation results, was poor due to the high probability of severe snagging on the end of the rubrail section and the post to which it was attached.

Test Matrix Selection

Based on the Barrier VII simulation runs, it was concluded that the basic transition configuration had a high probability of passing NCHRP Report 230 test requirements. Simulation results indicated that the W-beam rail would yield locally in bending and tension, thus permitting some vehicle snagging to occur on the first steel blockout mounted on the concrete parapet. However, the degree of frame and wheel snagging predicted was not significant enough to impart unsatisfactory decelerations to the vehicle. Furthermore, predicted strains for the yielded rail did not exceed the rated ductility of the W-beam, indicating that rupture of the rail was unlikely. Additionally, deflected barrier shapes showed no evidence of vehicle pocketing, and the predicted maximum dynamic rail deflection was only 10 inches.

However, potential problems related to some of the design variations were identified. For instance, there was concern about the propensity for the W6x9 blockouts used in the steel post system to collapse under the combined longitudinal and lateral loading experienced during a transition test. Such behavior would tend to increase the lateral barrier deflection, resulting in increased vehicle snagging. On the other hand, simulation results for the wood post system indicated that the shear capacity of one or more posts in the transition could be exceeded due to combined longitudinal loads from the W-beam and channel rail elements. Failure of this type would significantly increase barrier deflection and could result in vehicle pocketing, severe decelerations, or other unacceptable results. For this reason, the steel post system with channel rubrail was deemed to have the highest probability of passing NCHRP Report 230 test requirements and was, therefore, the first transition system tested. It was believed that this test would not only provide a good assessment of the impact performance of the basic transition configuration, but would additionally examine the integrity of the concrete insert anchors to which the fabricated steel blocks and rubrail were attached.

As mentioned previously, the simulation results indicated poor impact performance for the upstream transition point. Considerable wheel snagging on post 7 (i.e. the post at which the rubrail began) and other intermediate posts was predicted for both the wood and steel post systems. This was due to the fact that post 7 was restrained at the top by the W-beam and at the bottom by the rubrail, thus decreasing deflections at this point and causing a pocketing behavior to occur. Of the two post types, the steel post system was considered to be more critical. The blockouts on the standard G4(2W) guardrail upstream from the transition are 8 inches in depth, as opposed to the 6 inch blockout distance provided by the W6x9 blockouts used in the standard G4(1S) guardrail. Thus, the predicted degree of snagging on the intermediate guardrail posts upstream from the transition was less severe for the wood post system. Furthermore, the wood post system utilized 8"x8" timber posts in the transition region which tended to "shield" the exposed end of the rubrail. In the steel post design, however, the rubrail end extends slightly beyond the end of the flange of the W6x9 steel post and, therefore, represented a more severe hazard. Additionally, as mentioned above, the W6x9 steel blockouts have a tendency to collapse during impact, thus increasing the degree of snagging on the post and rubrail end.

There was also concern regarding the performance of the transition with a curb. Analysis indicated that the curb would impart a significant vertical motion to the test vehicle. This vertical motion had the potential for raising the effective barrier loading height and, as a result, increasing the bending moments at the base of the guardrail posts. Such behavior would tend to increase barrier deflections and lead to increased vehicle snagging on the end of the bridge rail and first fabricated steel blockout.

The potential problems identified above were discussed with ADOT personnel. These and other factors were taken into consideration when formulating the test matrix used in the crash testing phase of this study. As needed, the test matrix was modified to incorporate testing of retrofit designs when standard systems were found to be deficient. Crash test procedures and test results are presented in detail in the sections which follow.

CRASH TEST PROCEDURES

The crash test procedures used in this study were in accordance with guidelines outlined in NCHRP Report 230. The test vehicle was instrumented with three rate transducers to measure roll, pitch, and yaw rates and a triaxial accelerometer near the vehicle center of gravity to measure acceleration levels.

The electronic signals from the accelerometers and transducers were telemetered to a base station for recording on magnetic tape and for display on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Contact switches on the bumper were actuated just prior to impact by wooden dowels to determine an elapsed time over a known distance. This information provided a measurement of vehicular impact velocity. In addition, the initial contact produced an "event" mark on the data record to establish the exact instant of impact.

Photographic coverage of the tests included three high-speed cameras, one perpendicular to the installation, one behind the rail pointing downstream of the impact point and a third camera located overhead near the point of impact. The films from these high-speed cameras were used to observe phenomena occurring during collision and to obtain time-event, displacement and angular data. A 3/4-inch video recorder and 35-mm still cameras were also used for documentary purposes.

Data Analysis Procedures

The analog data from the accelerometers and transducers were digitized, using a microcomputer, for analysis and evaluation of performance. The digitized data were then analyzed using the computer programs DIGITIZE and PLOTANGLE. The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, final occupant displacement, and highest 0.010-second average accelerations. The DIGITIZE program also calculates vehicle impact velocity, change in vehicle velocity at the end of a given impulse period, and maximum average 0.050-second accelerations along each of three primary vehicle axes.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute and plot angular displacements versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented in this report. Furthermore, the displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system corresponding to the conditions which existed at initial impact.